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ABSTRACT

Although the distinction between verbal ability and spatial ability is fundamental in all models of human abilities, differences in the relative strengths of verbal and spatial abilities have failed to show consistent interactions with instructional treatments. This study investigated the hypothesis that spatial tests measure different abilities in different subjects and so replicable Aptitude X Treatment interactions (ATI) with spatial ability are unlikely. Forty-three subjects attempted 144 items from a spatial synthesis task previously shown to be a good measure of spatial ability. Componential models suggested that subjects differed in their solution strategies and that most subjects shifted strategies predictably over items. Correlations between task variables and reference tests showed that some solution methods relied more on verbal-analytic skills whereas other solution strategies relied more on spatial-analogy skills. Sex differences and implications for the measurement of spatial abilities are also discussed. (Author)

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The Role of Prior Knowledge and Strategy-Shifting in Spatial Ability

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Abstract

Although the distinction between verbal ability and spatial ability is fundamental in all models of human abilities, differences in the relative strengths of verbal and spatial abilities have failed to show consistent interactions with instructional treatments. This study investigated the hypothesis that spatial tests measure different abilities in different subjects and so replicable Aptitude X Treatment interactions (ATI) with spatial ability are unlikely. Forty-three subjects attempted 144 items from a spatial synthesis task previously shown to be a good measure of spatial ability. Componential models suggested that subjects differed in their solution strategies and that most subjects shifted strategies predictably over items. Correlations between task variables and reference tests showed that some solution methods relied more on verbal-analytic skills whereas other solution strategies relied more on spatial-analogy skills. Sex differences and implications for the measurement of spatial abilities are also discussed.

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Introduction

Why do spatial abilities show inconsistent interactions with instructional treatments (Cronbach & Snow, 1977)? These inconsistent interactions are especially puzzling in view of the prominent position of spatial abilities in all models of human abilities (Lohman, 1979a). Perhaps we do not understand spatial abilities well enough to measure them accurately or to design instructional treatments that demand particular spatial skills or compensate for their absence. Correlational studies of performance on spatial tests suggest that there are many different spatial abilities and that these different abilities can be ordered hierarchically, at least approximately. Two types of mental transformations are required by tests that load on the General Visualization Gv (or Vz) factor at the apex of this spatial-factor hierarchy. The two transformations are movement (rotating, reflecting, folding, transposing, etc.) and synthesis (or its opposite, decomposition). Movement transformations, especially rotation, have been studied extensively; synthesis transformations are less well investigated but equally prevalent in spatial task performance. In previous experiments (Lohman, 1979b ; Kyllonen, Woltz, & Lohman, 1981), I studied the independent and combined effects of synthesis and rotation transformations. Componential analyses of the synthesis trials on this task suggested that different subjects solved different items in predictably different ways. More importantly, subjects appeared to shift strategies over items. Further, variations in solution strategies were systematically related to aptitude profiles of subjects (Kyllonen, Woltz, & Lohman, 1981). However, only males were included in the sample, and synthesis was not the only transformation required in the experiment. Therefore, our goals here were to include females in the sample, to include only synthesis trials, to simplify and refine the task, and to replicate and extend our previous findings that subjects shift strategies across items on this, and by implication, other complex spatial tasks.

Method

Materials

On each trial, subjects were required to memorize one stimulus (the "A" figure), combine this stimulus with a second figure ("B"), and then indicate whether a third stimulus ("C") was correct synthesis of the A and B stimuli. (see Figure 1). Foils differed only in a 20%, 40%, or 60% alteration of the proportions of the correct probe, and thus were quite similiar to correct probes. Only one figure was visible at a time, and each appeared in a different third of the video monitor. After accepting or rejecting the probe, S's indicated confidence in their response on a three-point scale. Thus, three latencies, a discriminative response, and a confidence judgment were recorded for each trial. In all, two parallel blocks of 72 items were presented.

Subjects were 43 University of Iowa undergraduates who participated for course credit. Most were sophomores, and 32 were female.

Four reference tests were also administered to each subject in a group session. The tests were: Extended Range Vocabulary (French Kit), Terman Concept Mastery (Verbal analogies only), Card Rotations (French Kit) and Form Board (French Kit).

Results

How do subjects memorize A, synthesize A and B, and compare their image with a test probe C? Before we attempted to answer these questions, we first checked the overall validity of the task. In a prior study errors were highly correlated with reference spatial tests, whereas time to solve items was generally more related to verbal abilities than to spatial abilities. However, similiar correlations between errors, latencies, and reference tests in this experiment were not significantly different from zero. Why? Perhaps changes in the experimental task, or the shift from an all-male to a primarily female sample, or the use of conscripted subjects was the culprit. We suspected that the major factors were that some subjects were poorly motivated and that, in spite of our efforts to simplify the task, items were generally much more difficult for these subjects than we had expected and so many subjects had resorted to non-spatial strategies. Nevertheless, we were convinced that this task was a good measure of spatial ability for some subset of the sample. The question, then, was whether componential analysis would allow us to identify these subjects.

Memorization of A

Three single-strategy models and two strategy-shift models were tested for each subject. The models were: feature anlaysis, in which the subject stored "A" as an organized set of features; labeling, in which the subject generated a nongeometric label for the stimulus; decomposition, in which the subject decomposed complex shapes into simplier shapes; label-decomposition shift, in which the subject either labeled or decomposed stimuli, which ever was easier; and label-feature analysis, in which the subject either labeled each figure or stored the stimuli as an organized set of features. The results are shown in Table 1. Here subjects are classified according to which model best fit their latencies. Adjusted R^2 ranged from .10 to .66. Ss with adjusted R^2's less than .20 are excluded from the table. Decomposition was clearly the preferred model (or strategy) in Block 1, whereas the label-feature shift model showed a slight edge in Block 2. Both models suggest that memorization of unfamiliar stimuli is an active process of imposing prior knowledge of forms (decomposition) or knowledge of forms and of more concrete stimuli (label-decomposition shift) on the to-be-remembered stimuli.

Next, we recomputed correlations between memorization latencies, correctness weighted for confidence, and a within-model estimate of short-term memory capacity (Storage-Shift point). Although full-sample correlations between these variables and the four reference tests were not significant, correlations computed within strategy groups were significant, but generally opposite for the two major strategy groups. Some of these correlations are shown in Table 2. Here, we averaged the within-block correlations for simplicity. Table 2 shows that, for Ss using the decomposition strategy, memorization latency was highly correlated with vocabulary, correctness with Form Board, and "chunk size" negatively with Form Board.

Correlations for the label-decomposition shift group were more mixed, but generally opposite in sign. Indeed, correctness was significantly correlated with Verbal Analogies. Thus, for those who decomposed complex stimuli into simplier forms, the task was a good measure of spatial ability (although latency was still more related to verbal ability). Further, high-

spatial subjects tended to decompose figures into many simple shapes. Subjects in the label-decomposition shift group, however, appeared to rely more on verbal and verbal reasoning skills to solve items. Thus, failure to obtain significant correlations for the full sample was partially due to the fact that two different, in fact, quite contrary strategies were employed by different subjects to memorize the A figure.

Synthesis of A and B

How did subjects mentally synthesize stimuli? What did they do when they were unable to integrate the separate stimuli into a coherent image? Models for the synthesis step differed along two major dimensions: first, whether Ss always, sometimes, or never synthesized figures, and second, how they attempted to remember the synthesized image or the unsynthesized stimulus pieces. Figure 2 shows the general model in flow-chart form.

R^2's varied from .15 to 59 in each block. No one was best-fit by the "always" synthesize model. In fact, models suggested that many Ss did not synthesize the figures at all. Only 14 Ss in the first block and 18 Ss in the second block synthesized approximately half of the figures. Further, unlike the memorization step, most subjects were best fit by the label-decomposition storage model, with decomposition in second place.

Once again we computed correlations between reference tests and dependent measures within strategy groups. In Block 1 for Ss best-fit by the label-decomposition storage strategy, synthesis latencies were significantly correlated with Vocabulary (r = .43), whereas correctness was signficantly correlated with Form board (r = .38). By Block 2, correctness scores for this group were most highly correlated with Verbal Analogies (r = .36, $p < .05$). Thus, errors and latencies are not interchangeable aspects of performance on spatial tasks (Egan, 1979). In fact, latencies often show stronger correlations with verbal abilities and errors show stronger correlations with spatial abilities (Lohman, 1979b). However, synthesis latencies were significantly correlated with spatial ability for those subjects identified as synthesizing items. These subjects showed an average correlation of -.57 ($p < .05$) between synthesis latency and Form Board (cf. Lansman, 1981). Thus, although full sample relationships between dependent measures and reference tests were not significant, sensible and significant relationships emerged when correlations were computed within strategy groups.

Comparison

Models for the comparison step (Figure 3) differed in whether subjects were assumed to have synthesized figures successfully. As in previous research, model fits here were generally lower than for other task steps (R^2 ranged from .05 - .47). However, there was substantial agreement between the synthesis-step models and the comparison-step models on whether subjects had in fact synthesized figures. For 35 subjects the models agreed, whereas for 8 they disagreed whether S's had synthesized some of the figures or none of the figures. For those 21 subjects reasonably well-fit by a comparison-step model, latencies were significantly related to Form Board (r = .55, $p < .01$) in Block 1, but were independent of all reference tests in Block 2.

Other findings

Models for errors suggested that most of the predictable errors were introduced (perhaps artifically) at the comparison step. For 9 subjects with R^2's greater than 30 for these error models, memorization-step predictors accounted for 3.7% of the variance, synthesis-step predictors accounted for 8.8% of the variance, and comparison-step predictors accounted for 24.7% of the variance.

Males made significantly fewer errors but were not faster than females. Most strategy differences between sexes occurred in the second block, with males employing the more "spatial" strategy. However, males also appeared to exhibit greater bravado, especially when rejecting a probe.

Conclusions

Some of the major results and implications of this study are:

1. Minor changes in format and sample drastically altered relationships between this task and other tasks (cf. Glushko & Cooper, 1978).

2. Componential analysis proved to be a powerful method for untangling the mess.

3. In most cases, strategy-shift models fit better than single-strategy models.

4. The most important point may not be the exact nature of the models, but the nature of the cognitive system that must be posited to account for this diversity.

5. The cleanest split between strategy groups was formed when subjects were classified by how they represented the initial stimulus. The key difference here appeared to be what type of prior knowledge they brought to bear on the task of memorizing the "A" figure and how thoroughly they decomposed the figure. Process and representation are inextricably intertwined, yet these results suggest future studies of spatial abilities attend more carefully to the nature of the processes used to establish an initial representation of an unfamiliar figure, and the characteristics of that representation.

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Table 1

Models for Memorization of "A"

Model	N Best fit by model Block 1	Block 2
Single-Strategy Models		
Feature Analysis	4	2
Labeling (nongeometric)	0	0
Decomposition	22	15
Strategy-Shift Models		
Label-Decomposition	10	17
Label-Feature Analysis	3	1

Table 2

Average Correlation over Blocks between Memorization Latency, Storage-shift point, and Correctness-Confidence Score and Reference Tests for Memorizaitor. of "A" Models

Decomposition Strategy[a]

	Memorization Latency	Storage Shift	Correctness-Confidence
Form Board	.25	-.47*	.52*
Cards	.00	-.35	.23
Vocabulary	.57*	.28	.17
Verbal Analogies	.16	.15	.28

Label-Decomposition Shift Strategy[b]

Form Board	-.16	.39	-.08
Cards	.22	.34	-.15
Vocabulary	.12	-.15	.28
Verbal Analogies	-.02	-.18	.48*

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[a] n = 10 to 20

[b] n = 11 to 19

Table 3

Number of Subjects with $R^2 > .20$ Best Fit by Each Model for the Synthesis Step

	Block 1		Block 2	
Percent of Items Synthesized	0	50	0	50
Model for Storage				
Feature-Analysis	0	0	0	0
Decomposition	4	1	8	3
Label-Decomp. Shift	19	13	11	14
Label-Feature Shift	0	0	3	1

Table 4

Average Correlation over Blocks between Synthesis Latency, Storage-Shift Point, and Correctness-Confidence Score, and Reference tests for Subjects Actually Synthesizing Figures.

	Synthesis Latency	Storage Shift	Correctness Confidence
Form Board	-57*	33	29
Cards	-15	-08	34
Vocabulary	30	-46*	08
Verbal Analogies	45	-25	11

Note. n=21

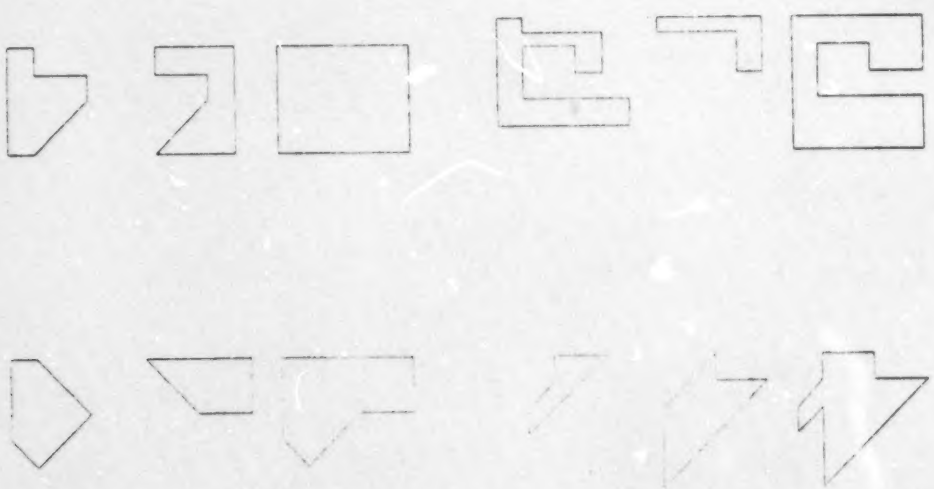

Figure 1. Examples of experimental trials.

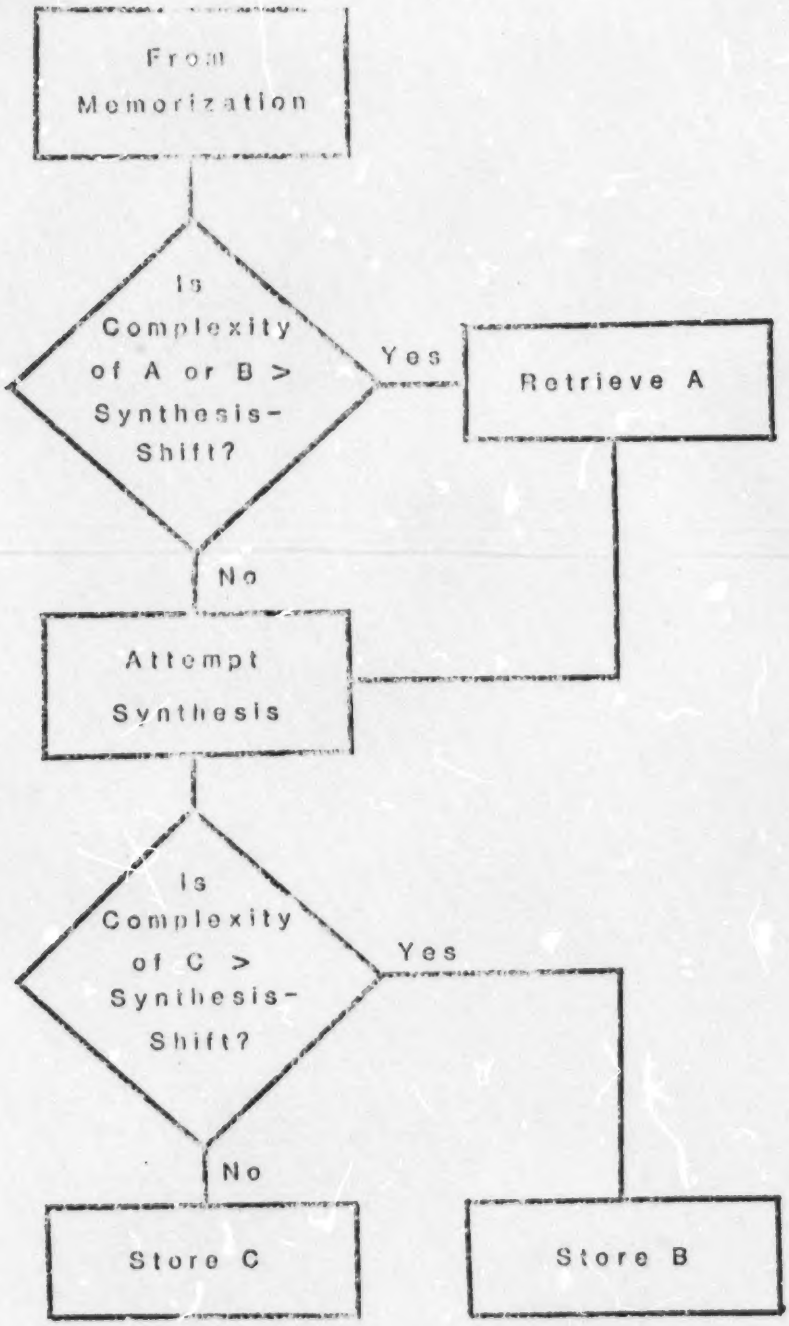

Figure 2. Basic model for the synthesis step.

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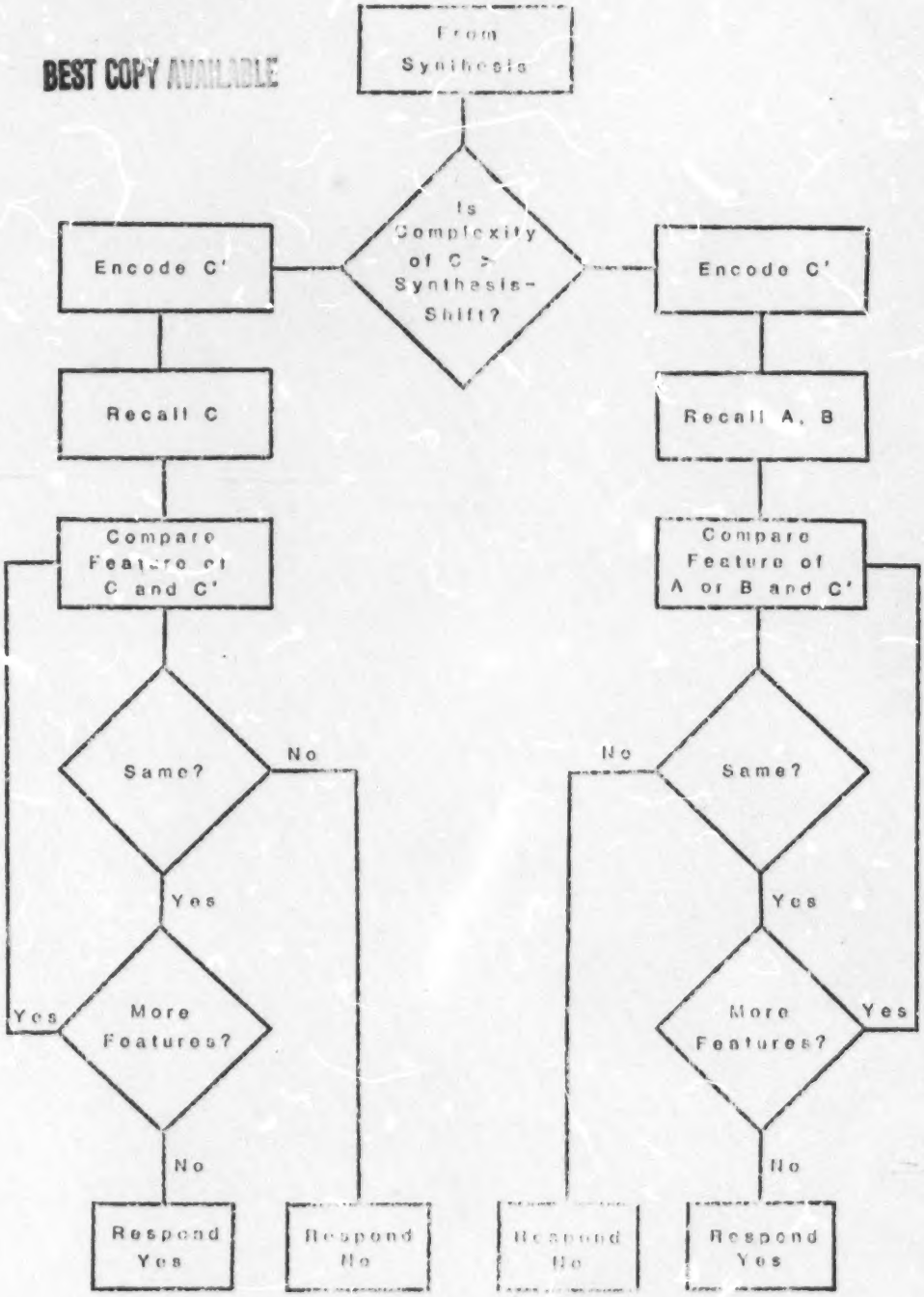

Figure 3. Basic model for the comparison step.